Capacity and Energy Usage of Translucent and Multi-Band Transparent Optical Networks

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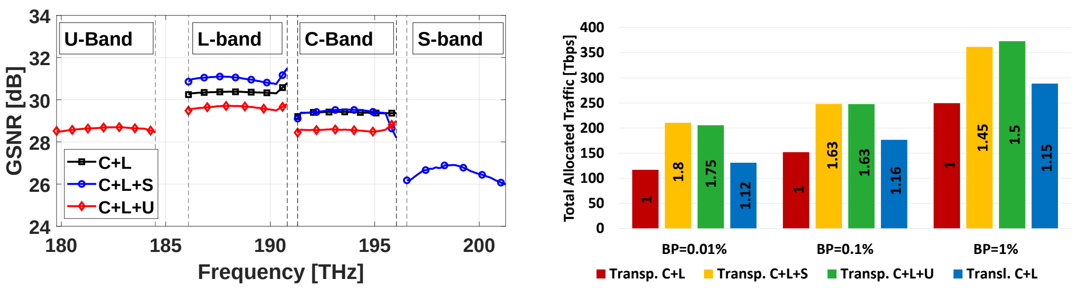
Abstract: This work shows that exploiting more bands in a transparent network design is a more effective and power-efficient way to increase the network capacity instead of relying on signal regenerators to increase spectral efficiency.

1. Introduction

As the telecommunications industry experiences fast growth in data traffic, the demand for increasing the capacity of Wavelength Division Multiplexing (WDM) systems becomes more important. Current WDM systems mostly utilize the 4.8 THz C-band, with few recent deployments also exploiting the C+L-band. Exploiting a even wider frequency range in the already deployed fibers, a solution designated as Multi-band Transmission (MBT), can extend the bandwidth of WDM systems to up to around 50 THz [1]. In the MBT approach, the bands with low losses such as L-, S-, and U-band are used to increase the network capacity. Alternatively, translucent network design can be used to increase capacity via signal regeneration at intermediate nodes [2]. In this case, Light Paths (LPs) are split into shorter ones as to support higher order modulation formats, thereby improving spectral efficiency [3]. However, the additional transceivers used to support signal regeneration can lead to increased Capital expenditures (CapEx). The recent OpenZR+ multi-source agreement (MSA) defines a cost-effective and power-efficient Transceiver (TRX) that operates at up to 400 Gb/s [4]. In this work, we utilized OpenZR+ TRx and performed a physical aware statistical network assessment for the USNET topology by progressively loading the network [5,6]. In the remaining of the paper, four different scenarios, namely transparent C+L, C+L+S, C+L+U, and translucent C+L are compared in terms of capacity and energy consumption. The results provide evidence of the benefits of exploiting an additional band for transmission, while preserving a transparent network design approach.

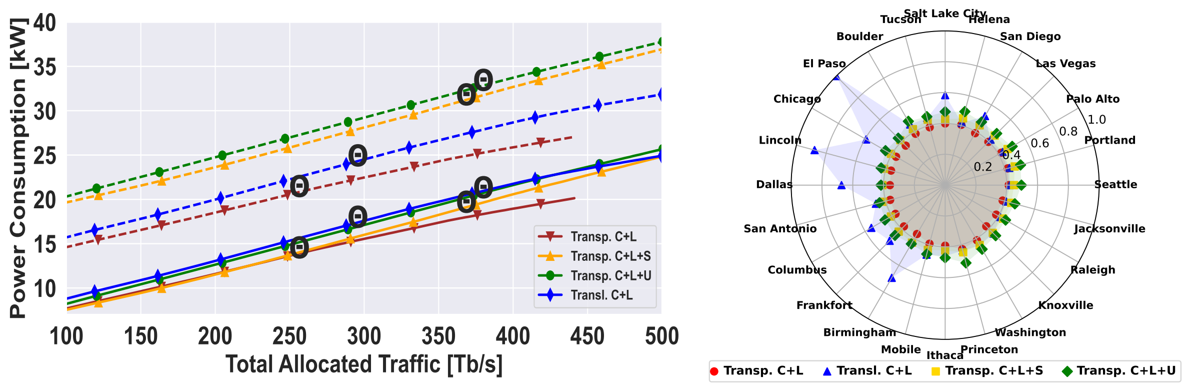
2. Methodology and Results

In an optical network, a LP performance can be modeled based on both Gaussian disturbances and nonlinear interference (NLI). The former is due to the amplified spontaneous emission (ASE) noise introduced by the optical amplifiers and the latter is caused by the fiber propagation. At the end of each fiber span, which is assumed to be Standard Single-Mode Fiber (SSFM) with 75km in this work, the Generalized Signal-to-Noise Ratio (GSNR) can be calculated and used as the main quality of Transmission (QoT) metric [6]. Moreover, to evaluate the NLI effect the Generalized Gaussian Noise (GGN) model is used, which considers both spectral and spatial variation of gain/loss and its interaction with the stimulated Raman scattering (SRS) effect [7]. The QoT is determined by $\mathrm{GSNR}_{i,\mathrm{total}} = 1/\sum_{s\in L}(\mathrm{GSNR}_{i,s})^{-1}$, where $\mathrm{GSNR}_{i,s}$ is the GSNR of the i^{th} frequency on span s of the LP. The average Noise Figure (NF) values for C-, L-, S-, and U-band amplifiers are assumed to be 4.3 dB, 4.7 dB, 6.5 dB, 6 dB, respectively. For each band, 64 channels on the ITU-T 75 GHz grid are considered with a symbol rate of 64 Gbaud. The GSNR profile for three different configurations (C+L-, C+L+S-, and C+L+U-band) is depicted in Fig. 1(a). The average GSNR value after a single span for the C- and L-band, in the C+L-band configuration, is equal to 29.4 dB and 30.4 dB, respectively. The latter value changes to 31 dB in the C+L+S-band configuration, in



(a) (b)

Fig. 1: (a) Frequency versus GSNR for the C+L-, C+L+S- and C+L+U-band scenarios, and (b) total allocated traffic versus three different targets BPs for the USNET topology.



(a) (b)

Fig. 2: (a) Energy consumption versus total allocated traffic without (solid curves) and with (dashed curves) amplifiers power consumption (BP of 1% marked with θ) and (b) consumed energy for each node in different scenarios at the same allocated traffic, 250 Tb/s.

which case the GSNR value in the S-band is 26.5 dB. In the C+L+U-band configuration, the average GSNR value is 28.6 dB, 29.6 dB, and 28.6 dB for the C-, L-, and U-band, respectively. For the network analysis, the USNET topology is progressively loaded with connection requests of 100 Gb/s. As per OpenZR+ MSA, each TRX supports three different modulation formats (16QAM, 8QAM, and QPSK), resulting in three different bit-rate (400, 300, and 200 Gb/s), power consumption figures (20, 18, 16 Watt) and Required GSNR (RGSNR) [4, 8]. Note that the utilization of the translucent network design approach consists of selectively deploying additional transceiver pairs to guarantee that end-to-end connections always support the highest data rate (i.e., 400 Gb/s). In Fig. 1(b), the total allocated traffic and multiplicative factor of network capacity (with respect to the baseline C+L-band case) are shown for a target Blocking Probability (BP) of 0.01, 0.1, and 1%. According to this figure, signal regeneration in the C+L-band translucent network leads to an average increase in network capacity of 14%. Conversely, network capacity is increased by around 62% for both C+L+S- and C+L+U-band transparent networks. The average energy consumption of each network with and without consideration of optical amplifiers' power consumption is depicted in Fig. 2(a). The average length of the network links connecting a pair of ROADMs is 308 km and a total of 173 optical amplifiers was considered for each band with a power consumption of 20, 20, 30, and 30 Watts for the C-, L-, S-, and U-band, respectively. According to Fig. 2(a), when considering only the transceivers contribution, the power consumption of the network in the transparent C+L, C+L+S, C+L+U, and translucent C+L is equal to 13.67, 13.67, 15, and 15.39 kW at the delivered traffic of 250 Tb/s, respectively. However, the average power consumption of the network grows about 9.5 kW by factoring in the amplifiers' power consumption. Precisely, the power consumption in the transparent C+L, C+L+S, C+L+U, and translucent C+L is equal to 20.6, 25.84, 27, and 22.36 kW at the delivered traffic of 250 Tb/s, respectively. To provide more insight into the energy consumption, Fig. 2(b) is presented at the same delivered traffic of 250 Tb/s for all four configurations. This figure shows that the average nodes' energy consumption in the C+L-band transparent network is less than the other scenarios (red circles). Moreover, the average nodes' energy consumption in the C+L+S- and C+L+U-band transparent networks are almost the same with only a small difference (Yellow and Green markers). On the contrary, the utilization of 3R regenerators in intermediate nodes to improve spectral efficiency (translucent design) results in an increase of the nodes' energy consumption, particularly visible in nodes that due to their location are natural candidates to host regenerators. This trend is visible, for instance, in *El Paso, Lincoln, Chicago, and Dallas*.

3. Conclusion

We showed that network performance in terms of capacity and energy consumption in a transparent network design exploiting an additional transmission bands is more effective than employing a translucent network design. Moreover, not only selective signal regeneration provides limited increase in capacity, but also results in very disparate energy consumption figures across the network nodes.

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